Dear Colleagues,

Thanks for your questions to reassess the needed parameters for the ILC. We would like to answer a bit more general than your original question. The physics potential of Electroweak and Alternatives is much more broad than finding a Z` from $e^+e^- \rightarrow$ffbar:

- Triple gauge couplings: These couplings are highly sensitive to strong electroweak symmetry breaking and also to loop corrections e.g. from SUSY. In addition most Z` couple to WW and thus should modify the TGCs. This means even in the Z` scenario the TGCs are needed to disentangle the models.

- Vector boson scattering and 3-V production: This is the essential channel for strong electroweak symmetry breaking.

- Extra dimensions: There are many models of ED but the common feature is that one has to separate vector particles and tensor particles.

- Contact Interactions: There are many scenarios where new physics will reveal itself at the ILC indirectly via deviations from the Standard Model predictions for production processes. Examples include extra gauge bosons, compositeness, extra dimensions, string excitations, leptoquarks, and R-parity violating Supersymmetry. The focus of the ILC is to determine which model is responsible for the deviations – in most cases this is accomplished by determining the spin of the particle being indirectly exchanged.

- GigaZ: There are many studies that show how important GigaZ may be in several scenarios.

Before we go into detail let us explain some facts about polarization:

In the case where only vector particles are involved in principle the polarization of one beam is sufficient; however many of the scenarios listed above under the category of contact interactions involve the exchange of spin-0 or 2 particles. In fact, there are two INDEPENDENT benefits of polarizing both beams.

First, the effective polarization is increased when both beams are polarized. In case of the left-right asymmetry (which is an essential observable in the identification of new physics models) the effective polarization is p_{eff}=(p+ - p-)/(1-p+·p-) which is 95% for p-/p+ = 80%/60%. If A_{LR} has a moderate value (*i.e.*, the $\sqrt{}(1-A_{LR}^2)$ term can be neglected in the error evaluation) this results in a 15% decrease in statistical error which is not a particularly large effect. The situation is, however, completely different if A_{LR} takes on a large value or if you want to measure properties, such as angular distributions of the events. The fraction of wrong versus right polarization, *i.e.*, the fraction of contamination from the undesired polarization state, is p_w=(1-p)/(1+p) for one beam polarized and p_w=(1-p-)·(1-p+)/((1+p-)·(1+p+))for both beams polarized. Putting in numbers you get:

P-/P+	***0***	***0.6***
0.8	0.11	0.028
0.9	0.053	0.013
0.95	0.026	0.006

where you see that signal to background for p-/p+=80%/60% improves by a factor of 4 with respect to the 80%/0% case and it is almost same as the case for 95%/0%. This is very relevant e.g. for the triple gauge coupling measurements where the right-handed cross section is much smaller than the left-handed one, or in the search for right-handed Ws in single photon events.

Second, is the issue of error reduction. For A_{LR}, the error from polarization is given by dA_{LR}/A_{LR} = dP/P and the error from statistics is $dA_{LR}=1/\sqrt{}N$. For A_{LR}=0.5 a very good 0.25% polarization measurement is comparable to the statistical error from only 640,000 events. With positron polarization, the error on p_{eff} is much smaller due to error propagation. If the polarimeter errors of the two beams are independent, then the error is reduced by a factor 4 with p-/p+ = 80%/60%. Even if the errors of the polarimeters are fully correlated, the reduction is still a factor 3. Higher electron polarization doesn't help at all with error reduction. With the Blondel scheme, spending some time on the J=0 states gives even smaller errors.

For some cases, such as the identification of spin-2 exchange in models with extra dimensions, transverse polarization is useful. However, in the cross section formulae transverse polarization enters as the product p_t(e-)·p_t(e+) so that measurements of observables with transverse polarization dependence definitely requires the polarization of both beams.

Detailed answers to the Z' questions:

The indirect exchange of a heavy Z’ boson can be described by a dimension-6 contact interaction. If a Z’ is observed at the LHC and its mass is well measured at ATLAS and CMS, then the achievable sensitivity for the determination of its couplings scales with center-of-mass energy and luminosity for the ILC as $(sL)^{1/4}$. This same scaling law applies for the search reach for the Z’ mass. This implies that the coupling (and search reach) sensitivity is essentially statistics dominated. In addition, for the case of positron polarization with p-/p+ = 80%/60% the gain in coupling (or search reach) sensitivity corresponds to a 10-18% increase (with the exact number being model dependent) over the case without positron polarization. This is equivalent to a 20-40% increase in center-of-mass energy for the accelerator. For 500 GeV running, at least 500 fb^{-1} luminosity with 60% positron polarization or 800 fb^{-1} without positron polarization would be necessary to exceed the sensitivity expected for LHC.

The couplings for a Z’ boson can only be measured for leptons in a model independent way. The luminosity can probably be determined to 0.1% and the detection efficiency to about the same error for lepton final states. With $1ab^{-1}$ the statistical error on the cross section is 0.16%, approximately matching the systematic error. For the forward backward asymmetry, which is an important input to the Z’ coupling determination, the systematic error should be extremely small. The left right asymmetry usually has a very important contribution to the error from the polarization measurement which is proportional to A_{LR} as discussed above. However, since A_{LR} is very small for leptons this error is negligible. This means that the lepton asymmetries are statistics limited for all reasonable luminosities.

For the hadronic cross section, which is important for model dependent limits, the statistical error is 0.1% for $0.5ab^{-1}$, so that the statistical and systematic errors will be equal between 0.25 and 0.5 ab^{-1}. For hadronic final states, A_{LR} is large (~0.5). If only electron polarization is available with a relative error of 0.25% the statistical and polarization error would be equal around $350fb^{-1}$. If positron polarization is available, the polarization error would be smaller by at least a factor three so that the matching point is around $1ab^{-1}$.

For the continuum processes beamstrahlung *a priori* is no problem. However, only a full simulation study can show if the increased acolinearity influences the selection procedure or the forward-backward definition. Such a study is not possible within the short time scale we have for this report.

Remarks on the other important channels:

As for the Z' at first sight none of the other channels appears particularly sensitive to beamstrahlung. However, detailed simulation studies are needed in all cases and are impossible to perform in the short time scale. The concerns are that events fall out of some cuts due to the acolinearity introduced by the beamstrahlung. For the TGC analysis mixed events are used where one W decays leptonically. The neutrino needs to be reconstructed from the missing momentum. This quantity degrades strongly due to beamstrahlung. This worsens also the resolution on the decay angles. In case of 3V production, beamstrahlung diminishes the possibility to do constrained fits for background rejection and WZ separation. Please keep also in mind that only a study from 2000 exists on how to measure beamstrahlung. This study used TESLA parameters with ideal beams. The result was that statistics is not a problem. However the concern is that systematic uncertainties exist from correlations. With ideal beams the correlations are only in the $3\cdot10^{-4}$ range for TESLA parameters, however this may be much worse with realistic beams and stronger focusing as in the low P parameter set.

For the case of indirect signatures of large extra dimensions, graviton exchange in $e^+e^- \rightarrow$ffbar can be described by a dimension-8 contact interaction. The sensitivity to such exchange scales with center-of-mass energy and luminosity for the ILC as $(s^3L)^{1/8}$. This implies that the search reach (and identification) sensitivity is essentially statistics dominated. In addition, for the case of positron polarization with p-/p+ = 80%/60% the gain in search reach (or identification) sensitivity corresponds to a 6% increase over the case without positron polarization. This is equivalent to a 10% increase in center-of-mass energy for the accelerator.

As stated above, positron polarization is useful to uniquely identify the presence of extra dimensions, versus a deviation in the Standard Model fermion pair production from other sources of new physics. If the ED scale turns out to be large, the transverse polarization asymmetry and angular distributions with longitudinal polarization of the final state fermion pair provide a means to uniquely distinguish a Z' boson from extra dimensions. In addition, the angular distributions of pair production of Higgs bosons and gauge boson pair production are also useful observables for distinguish spin-1 and 2 exchange. In fermion pair production, roughly speaking, up to the scale where you can just exclude the SM with longitudinal polarization you can separate Z' and ED with transverse pol – this corresponds to mass scale of roughly $10\sqrt{s}$.

For TGCs positron polarization is needed to increase the effective polarization. It has been shown that 80% electron polarization 60% positron polarization decreases the error by 40% in some cases, which is equivalent to a factor two in running time. Polarimetry seems to be not an issue for the TGCs since the polarization can be obtained from the forward t-channel peak. The total W-pair statistics is huge (few million events). However, larger scattering angles are suppressed by more than two orders of magnitude so that even with conservative estimates of systematic uncertainties the measurements should be statistics limited. The same suppression is true for right-handed polarization.

Vector boson scattering is strongly limited by statistics so that positron polarization enhances the effective cross section. 3-V production for left-handed electrons has a very large SM component without the 4V vertex. Right-handed electrons reduce the error dramatically. In addition, positron polarization helps a lot as an increase of the effective polarization. The most important ingredient is, however, the maximum possible luminosity.

If the different options for the ILC compete, for all processes mentioned above, apart from GigaZ, there is a clear ranking. The most important ingredient is a high center-of-mass energy, closely followed by high luminosity. Positron polarization is beneficial in all cases, but not as important as the other two.

Best regards,

JoAnne Hewett, Akiya Miyamoto, Klaus Mönig